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EVALUATION OF A CHEMICAL TECHNIQUE TO DETERMINE WATER AND CEMENT CONTENT OF FRESH CONCRETE

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This report presents information obtained from an evaluation of a chemical procedure for determining the water and cement content of a concrete in the plastic state. The procedure uses chloride ion titration to determine water content, and flame photometry (calcium signature) to determine cement content. This study evaluated the procedure to determine if it could be used to estimate concrete strength potential and to define to what extent test results are influenced by aggregate type, aggregate moisture conditions, aggregate absorption capacity, concrete mix proportions, mix time, and time of sampling. The field

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worthiness of the system was also evaluated.

Results indicate that the procedure can rapidly (approximately 15 minutes) determine the water and cement content of fresh concrete and that it can be used to predict strength potential with an accuracy equal to that of predicting strength from known mix proportions. Aggregate type was the only major concrete parameter that significantly influenced test results. Although aggregate moisture condition, mix proportions, and length of mixing time also influenced test results, their influences were minor. The field tests have indicated that the system is field worthy and mobile.

FOREWORD

This manuscript was prepared by the Construction Materials Branch of the Material Systems and Science Division, Construction Engineering Research Laboratory (CERL), for presentation at the January 1975 Transportation Research Board International Symposium on Recent Developments in the Accelerated Testing and Maturity of Concrete.

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COL M. D. Remus is Commander and Director of CERL and Dr. L. R. Shaffer is Deputy Director.

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TO DETERMINE WATER AND CEMENT CONTENT OF FRESH CONCRETE

1 INTRODUCTION

Inspection and testing procedures currently being used to determine the quality of concrete involve a time lag between concrete placement and the evaluation of concrete quality (compression or beam tests). Also, the current tests do not relate directly to either the material or the construction parameters that influence concrete quality.

This study evaluated the potential of a chemical technique originally developed by Kelly and Vail of the Greater London Council for rapidly determining the water and cement content of fresh concrete.[1] The study determines if the procedure can be used to estimate concrete strength potential and defines to what extent test results are influenced by aggregate type, aggregate moisture conditions, aggregate absorption capacity, concrete mix proportions, mix time, and time of sampling. The field worthiness of the system was also evaluated.

[1] R. T. Kelly and G. W. Vail, "Rapid Analysis of Fresh Concrete," Concrete (April 1968), pp. 140-145.

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2 DESCRIPTION OF PROCEDURE FOR DETERMINING WATER AND CEMENT CONTENT

The selection of analytical techniques for determining water and cement content was based on the criteria that the test should be rapid (less than 15 min), cheap, field worthy, and safe.

Water Determination. The method for water content determination is based on the theory that water in fresh concrete is available for intermixing with aqueous solutions. Thus, if an aqueous solution is of known strength and is not absorbed by the aggregate or the cement, the volume of water in a concrete sample can be determined analytically by determining the concentration of the intermixed solution. That is, if A is the volume of water in the mix, B and S_1 are the volume and strength, respectively, of the aqueous solution, and S_2 is the strength of the intermixed solution, then:

$$B \times S_1 = (A+B)S_2$$

From this equation, A can be calculated if B and S_1 are fixed and S_2 is measured. To measure the strength of the intermixed solution, the Volhard back-titration method is used with sodium chloride as the solute. When the concrete contains chloride from other sources, the procedure requires the use of both a sample and a blank. The Volhard back-titration method, with its white to reddish-brown end point, has the advantage of being accurate, rapid (average time required 7 min 30 sec), and simple enough for use by persons without analytical experience.

Figure 1 shows the equipment required for determination of water content. The equipment consists of a mechanical shaker; two wide-mouth plastic bottles; 10-ml, 5-ml, 2.5-ml, and 2-ml constant volume dispensers; two 50-ml and one 10-ml automatic pipettes; one 100-ml burette; two 50-ml volumetric pipettes; two 500-ml volumetric flasks; and two 500-ml Erlenmeyer flasks.

The procedure is accomplished as follows:

1. Weigh out two separate 1-kg samples of concrete and place each sample in a wide-mouth bottle. Add 500-ml of 0.5 N sodium chloride solution to one bottle (sample) and 500-ml of distilled water to the other bottle (blank).

2. Seal the bottles and place them in mechanical shaker; operate 3 min.

3. Remove the bottles from the shaker and allow the contents to settle for 3 min.

4. Pipette 50-ml samples of clear supernatant liquid from the sample and blank bottles and add to separate Erlenmeyer flasks. To each flask (sample and blank) add 10-ml of 50 percent nitric acid, 2-ml of nitrobenzene, and 5-ml of ferric alum. Shake well.

5. Determine the chloride content of the sample and blank flasks by adding excess silver nitrate (50-ml of 0.5 N $AgNO_3$ for sample and 10-ml of 0.5 N $AgNO_3$ for blank) and back-titrating with 0.05 N potassium thiocyanate (Volhard back-titration).

6. Record the quantity of potassium thiocyanate required to reach the white to reddish-brown end point in both the sample and the blank. Use Figure 2 to determine the water content of the mix.*

Cement Determination. The cement determination technique is based on the assumption that: (1) cement can be dispersed in water and held uniformly in suspension so that a representative sample can be obtained; (2) a quantitative solution of the cement in nitric acid can be achieved by adding cement to the acid while rapidly stirring without external heat; and (3) calcium can be determined by a flame photometer in relatively high concentrations in the nitric acid solutions without prior removal of silica and the sesquioxides.

Figure 1 shows the equipment required for the cement tests. The apparatus for preparing and sampling the cement-water suspension consists of a nest of sieves (No. 4 and No. 50) over a side-agitator domestic washing machine and three automatic pipettes. One pipette collects the constant volume cement-water sample from the washing machine; the others dilute the sample with nitric acid and water. An ordinary domestic high-speed stirrer (milk-shake type) provides agitation for dissolving the cement suspended in the acid solution. A flame photometer is used to determine the calcium (cement) concentration.

*Quantity of KCNS (ml) required for sample titration plus the back-titration of the blank (100 minus the KCNS required for blank titration) equals the abscissa of Figure 2.

Briefly, the major steps are as follows:

1. Fill the washing machine with 10 gal of tap water; place nest of sieves over the machine; start agitator and pump to recirculate water.

2. Place a 1-kg concrete sample on the nest of sieves and wash the cement from aggregate particles with the recirculating hose.

3. Allow agitation-recirculation operation to continue for 3 min. Attach the small hose to the automatic pipettes, then clamp the recirculating hose nozzle so that the cement suspension will flow through the small hose and fill the automatic pipette (125 ml).

4. Empty sample of cement suspension into a mixing cup and wash down the pipette with 100 ml of 5 percent nitric acid from the upper pipette. Concurrently, dilute acid-cement solution with 300 ml of tap water from the third pipette.

5. Stir contents of mixing cup on high-speed mixer for 3 min.

6. Calibrate the flame photometer with a calcium standard and measure the calcium content of solution in the mixing cup. See Figure 3 for converting readout to cement content. (Calcium standard is prepared to equal 1.5 gr/liter of cement, approximately 0.94 gr/liter of $CaCO_3$). The average time for a cement determination by an experienced operator is found to be 7 min 10 sec.

3 LABORATORY AND FIELD TESTS

Laboratory Tests. The laboratory test series evaluated three different aggregate combinations, three mix proportions, two mix times, and two aggregate moisture conditions. The three aggregate combinations were Maryland quartz (coarse and fine), sand and gravel, and sand and crushed limestone (Figure 4). The mix proportions (Table 1) represented approximately 3000, 4500, and 6000 psi concretes. A standard mix time of 5 min was used for each of the three mixes, and a second 4500 psi mix was tested using a 45-min mix time. The two aggregate moisture conditions were air dried and saturated with some surface moisture.

Two-cubic foot batches were used for all the series of tests. This was sufficient for a slump test and six 6-in. by 12-in. cylinders, in addition to the two 10-lb samples used for the water-cement analysis.

A complete standard water and cement analysis was run on both samples. The companion 6-in. by 12-in. cylinders were moist cured, three were broken at 7 days, and three at 28 days.

Field Tests. Field tests were conducted at two construction sites evaluating the mobility, reliability, and field worthiness of the system.

The test equipment was transported in a ready-to-use configuration in a pick-up truck type of camper shell (Figure 5). To be operational, the self-contained unit requires only water from an external source.

The field tests evaluated ready-mix delivered concrete of three aggregate combinations and three mix designs. The aggregate combinations were light-weight coarse aggregate and sand, siliceous gravel and sand, and calcarious gravel and sand. The mix designs represented a 3500-psi structural light-weight concrete, and a 4500 and 3000-psi normal weight concrete.*

The test procedure consisted of obtaining a water-cement content test sample from the same concrete that was used to prepare standard quality control cylinders. A complete water and cement analysis was run on all samples.

*The actual batch proportions were not checked for the 3500-psi and 4500-psi mixes because the batch plant was remote from the construction site and the water-cement test setup.

4 ANALYSIS AND DISCUSSION OF TEST RESULTS

Laboratory Tests. Data obtained from the water and cement tests on concrete samples were analyzed to determine overall accuracy and the influence of aggregate type, aggregate moisture condition, concrete mix proportions, mix time, and sampling on test results. Percent recovery (measured values divided by acutal values) was used as the basis of comparison and the water tests were related to both the free and total water content of the mixes.

Table 2 indicates that, for all samples, the average recovery for cement was 97.8 percent; free water, 96.6 percent; and total water, 85.7 percent. The associated standard deviations were: cement--8.1 percent, free water--4.4 percent, and total water--3.7 percent. The overall accuracy, including all the variables, was 8 and 4 percent respectively for the cement and water tests. Table 2 also indicates that the accuracies increased when each aggregate type was analyzed separately: the error in the cement tests decreased to about 6 percent and the error in the water tests decreased to about 3.5 percent.

An analysis of variance was used to determine which parameters influenced the amounts of cement and water recovered. The parameters included in the analysis were aggregate type (coarse and fine quartz, coarse limestone and river sand, and coarse gravel and river sand), aggregate moisture condition (saturated plus some surface moisture and air dried),mix proportions (representing nominal 3000, 4500, and 6000 psi design strengths),

mix time (5 and 45 min), and sampling sequence (sample obtained for water and cement content analysis before or after cylinder samples taken).

Results indicate that both the water and cement tests are sensitive at the 95 percent confidence level and significantly influenced by the aggregate type. Average recovery values for cement ranged from a low of 93.5 percent for the quartz aggregate to a high of 104.8 percent for the limestone aggregate. Average water recovery values based on free water varied from 94.2 percent for quartz aggregate to 100.2 percent for gravel; conversely, water recovery based on total water varied from 83.5 percent for gravel to 89.1 percent for quartz.

The high cement recovery value for the limestone aggregate concrete was attributed to the rock dust and limestone fines that passed through the nest of sieves above the washing machine. To confirm this, a cement test was conducted on a limestone aggregate sample representative of the limestone gradation and weight (420 gr) used in the concrete specimens. The 420 gr of limestone are equivalent to 12.5 gr of cement or an error of 1.25 percent cement. When this 1.25 percent is substracted from the cement test results, the mean cement recovery value for the limestone aggregate concrete is reduced to 96.59 percent.

In evaluating results of the water tests on the concrete samples, it was concluded that the test results are slightly more representative of free water than total water; the recovery values based on free water are in all cases much closer to 100 percent.

Strength Prediction Laboratory Results. Data obtained from the laboratory tests on concrete samples indicate that the chemical technique for determining water and cement content can be used directly to estimate the strength potential of a concrete mix. Figure 6 presents the 28-day cylinder strengths versus the water-cement ratios obtained in all batches tested. Figure 7 shows the 28-day cylinder strengths versus the actual water-cement ratios.*

Table 3 indicates the error associated with using the chemical technique to determine water and cement content as a measure of strength potential of a concrete. When all results are grouped together (Figure 6), the 80 percent confidence limits relating the chemically determined water-cement ratio to strength are ± 780 psi. When results are grouped by aggregate type (Table 3), however, the confidence bands decrease to ± 550, ± 500, ± 350 psi for the quartz, gravel-sand, and limestone-sand aggregate combiantions, respectively. Similar trends and improvements were also noted when strengths were compared to actual water-cement ratios (Table 3).

Table 3 compares the confidence limits for predicting strength by the actual and the chemically determined water-cement ratios. This comparison indicates that when all three aggregate combinations are grouped together, confidence bands for the actual and the chemically determined water-cement ratios are nearly equal (± 780 psi for the chemically determined

*Actual water content is based on free water available assuming the aggregates become saturated, and is determined by knowing the quantity of mix water modified by the moisture content of the aggregate for each concrete batch.

versus ± 720 psi for the actual). When the comparison is made individually by aggregate type, the spread of the confidence limits for the acutal water-cement ratio values is less for two of the three aggregate combinations.

Another variable evaluated was strength within a batch. Within-batch strength variations are normally associated with discrepancies in mixer efficiency, fabricating, curing, and testing. The within-batch variation obtained for the complete concrete test series was 196 psi for the 80 percent confidence limit.

All the above analyses indicate that the chemical procedure for determining water and cement content can be used to predict strength potential with an error no greater than if strength determination is based on the actual water-cement ratios of the mixes.

Field Tests. The field evaluations of the testing technique and the mobile unit have indicated that the unit can be transported with the automatic pipettes mounted in a ready-to-use configuration on the camper doors. Only one major equipment deficiency was noted during the field tests, the sensitivity of the flame photometer to external light. The use of a hood and side shields around the flame photometer decreased the sensitivity, but even with the hood and shield, calibrating and holding calibration during the determination of an unknown cement solution was difficult. Present procedures permit the operations of the flame photometer inside the camper.

Table 4 presents the results obtained from the field tests and compares them to those for the mix designs. For the water content test, results

indicate excellent agreement between the test results and the mix designs. The average recovery and associated standard deviation for the water test was 99.62 percent and 7.52 percent, respectively. The results from the cement test were not quite as encouraging. For the cement test, the average recovery was 94.39 percent and the standard deviation was 26.6 percent. It is assumed that the flame photometer's sensitivity to external light was partially responsible for the higher deviations. Also, the last 11 tests were conducted on a calcarious aggregate (both coarse and fine) concrete, requiring an aggregate blank test for removing the aggregate influence on the cement test results. This added another variable to influence cement test results.

The water-cement ratios obtained from the field tests were plotted against 28-day quality control cylinders. Figure 8 presents the field tests overlayed on the laboratory water-cement ratio versus 28-day cylinder strengths. The vast majority (12 out of 16) of the field tests fell near or within the 80 percent confidence limits of the laboratory test results. Of the four that fell outside, three were from the calcarious aggregate concrete. Even though the field data base is small and quite limited, the results indicate the potential of using the chemically determined water and cement content as a field test in evaluating concrete strength potential.

5 CONCLUSIONS

The results of this study indicate the following:

1. A chemical procedure has been developed that can rapidly (approximately 15 min) determine the water and cement content of a concrete in the plastic state.

2. The chemical procedure for determining water and cement content can be used to predict the strength potential of the concrete. The reliability of predicting strength by this procedure is nearly equal to that of predicting strength based on actual mix proportions.

3. Aggregate type (limestone, gravel, quartz, etc.) significantly influences the results obtained from the chemical tests. Although the chemical method is also sensitive to aggregate moisture condition, mix proportions, and the length of mix time, the degree of sensitivity is for all practical purposes insignificant.

4. Even though the chemical method is sensitive to the type of aggregate used, satisfactory results were obtained for concrete made from both gravel and limestone coarse aggregate.

5. The one major limitation of the chemical method is that the cement content technique decreases in accuracy if the fine aggregate or sand has a high calcium content. This occurs when a manufactured sand (crushed limestone) is used for the fine aggregate.

6. Field tests have indicated that the system is field worthy and mobile.

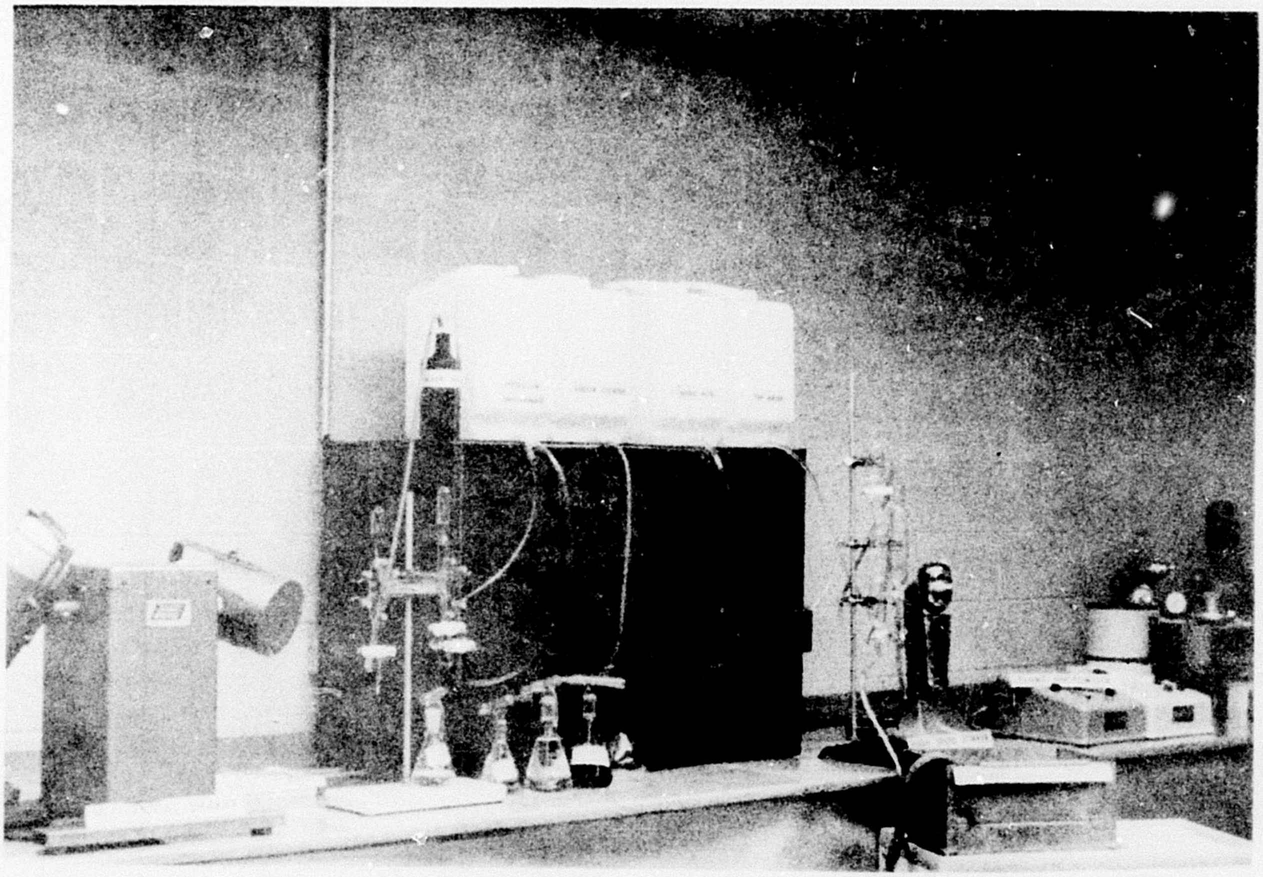

Figure 1. Equipment used in the Kelly-Vail procedure for determining the water and cement content of fresh concrete.

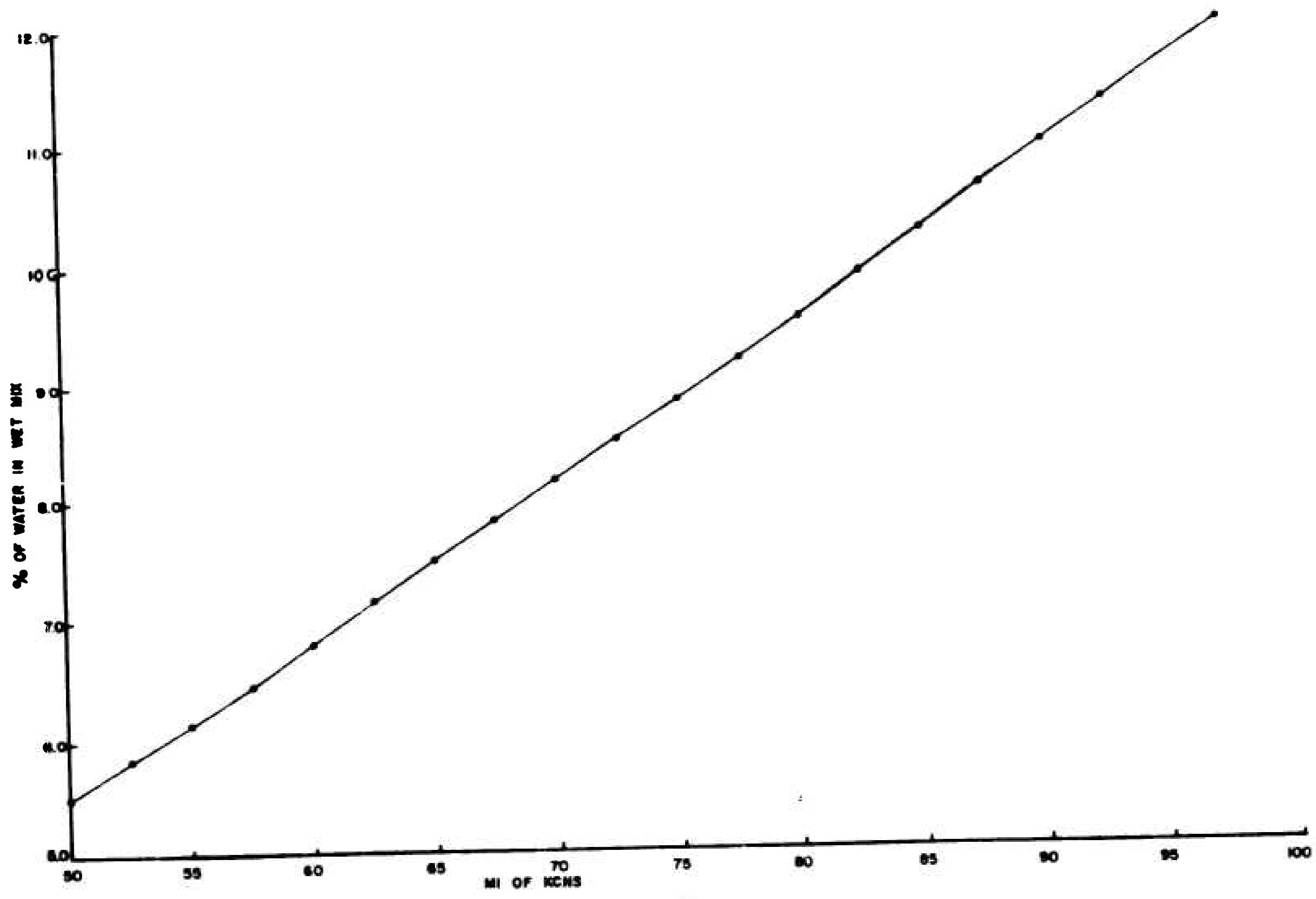

Figure 2. Water analysis.

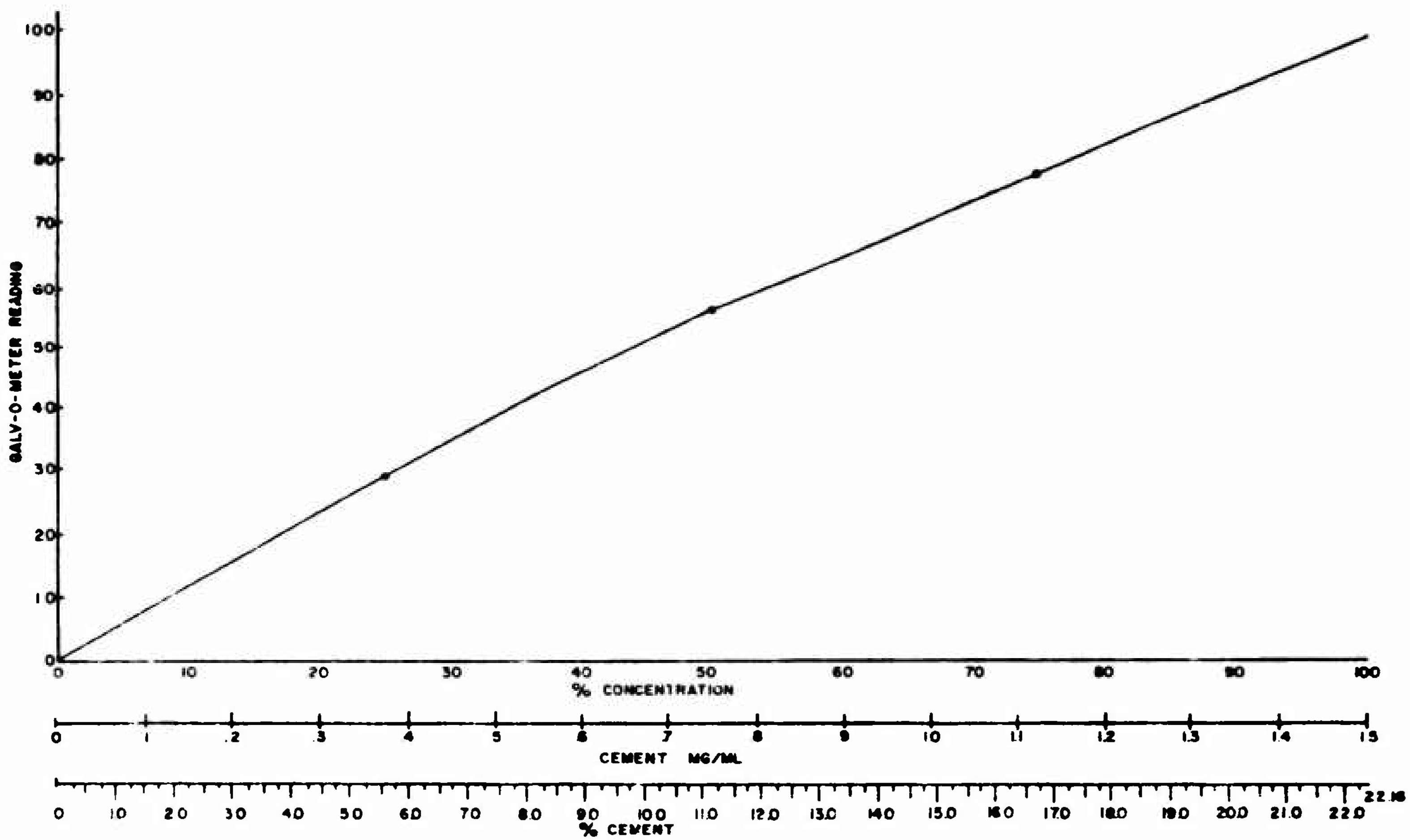

Figure 3. Cement analysis.

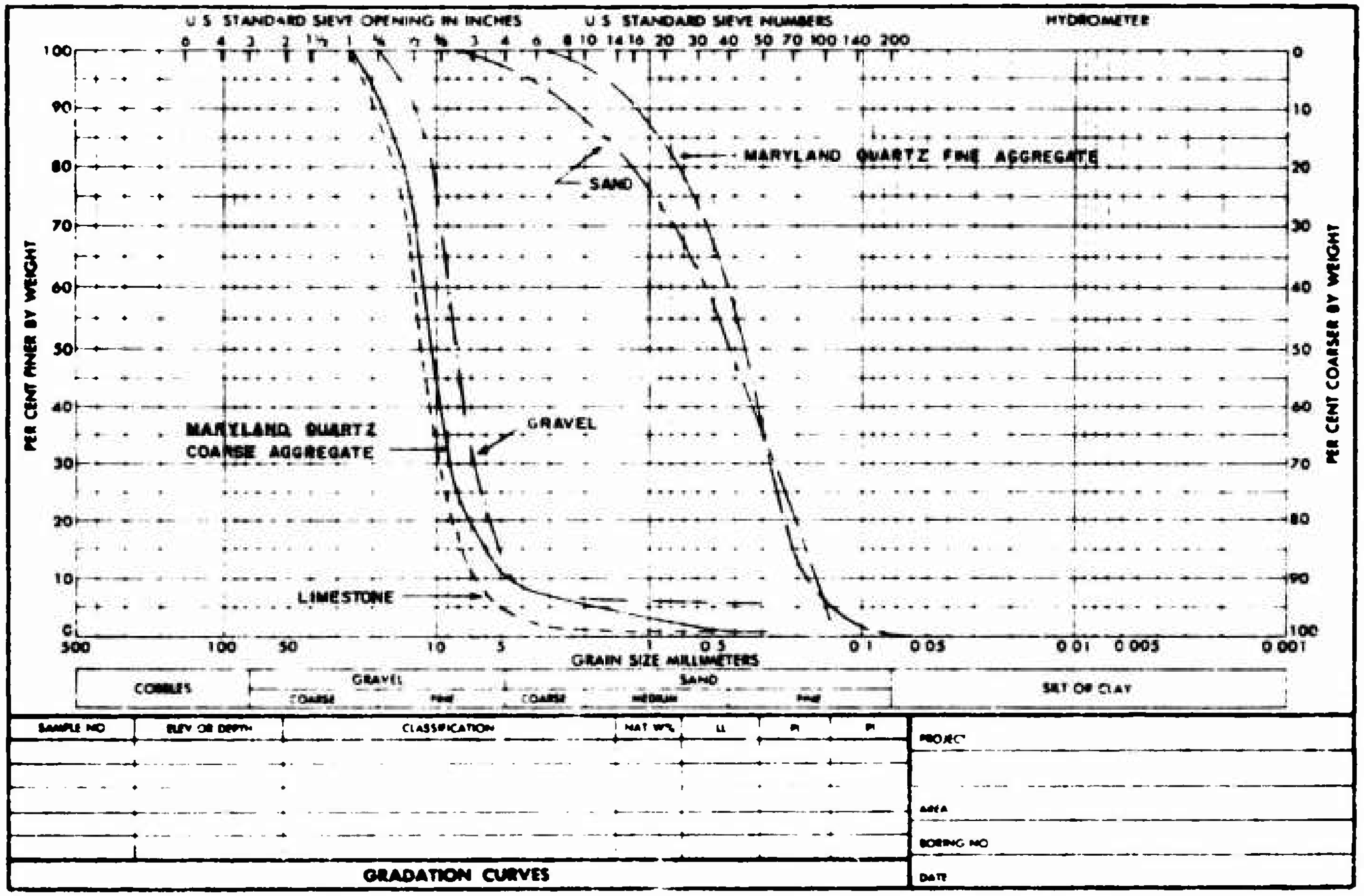

Figure 4. Aggregate gradations used in the concrete tests.

Figure 5. Field test equipment.

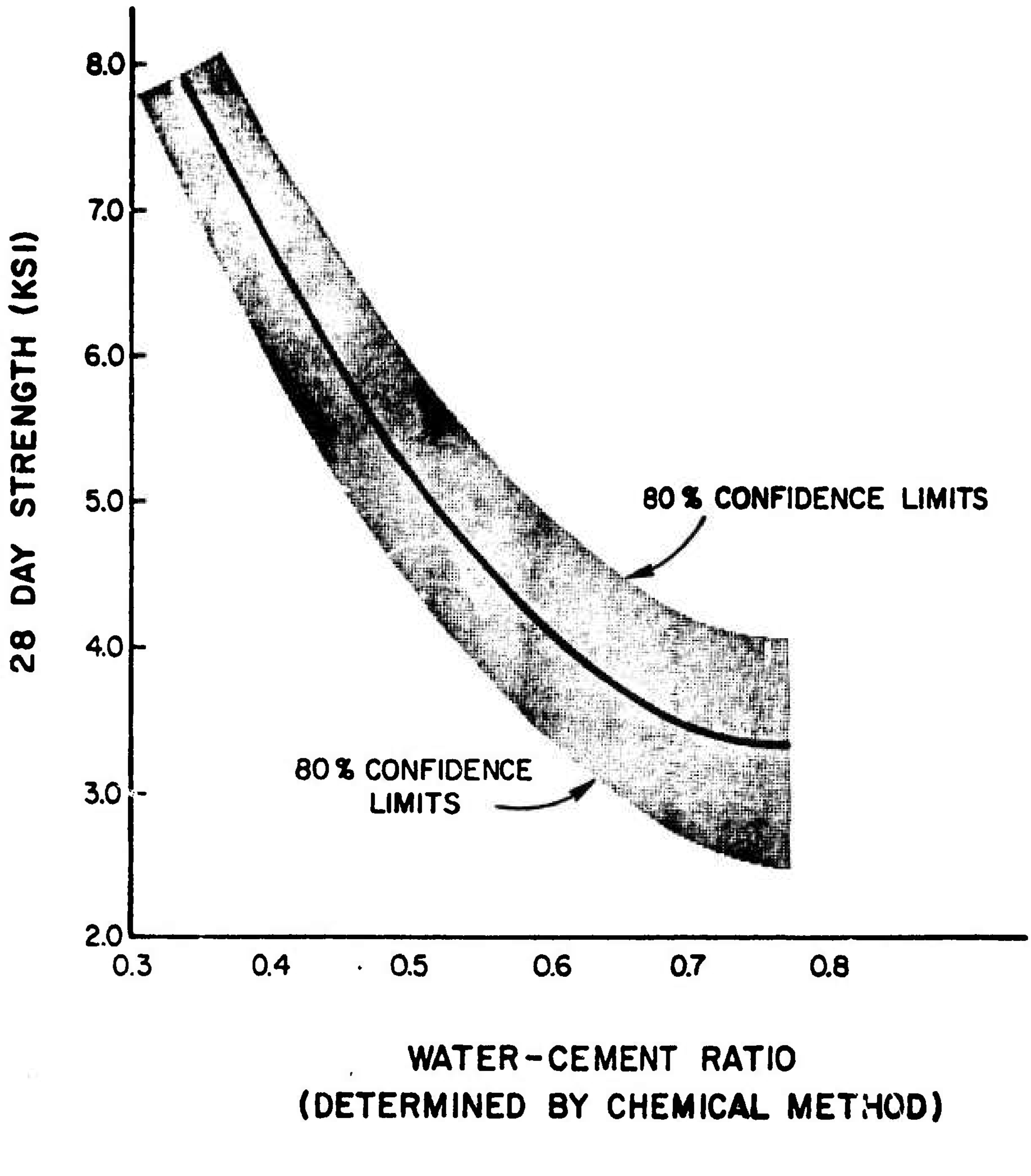

Figure 6. Water-cement ratio vs 28 day compressive strength (lab results).

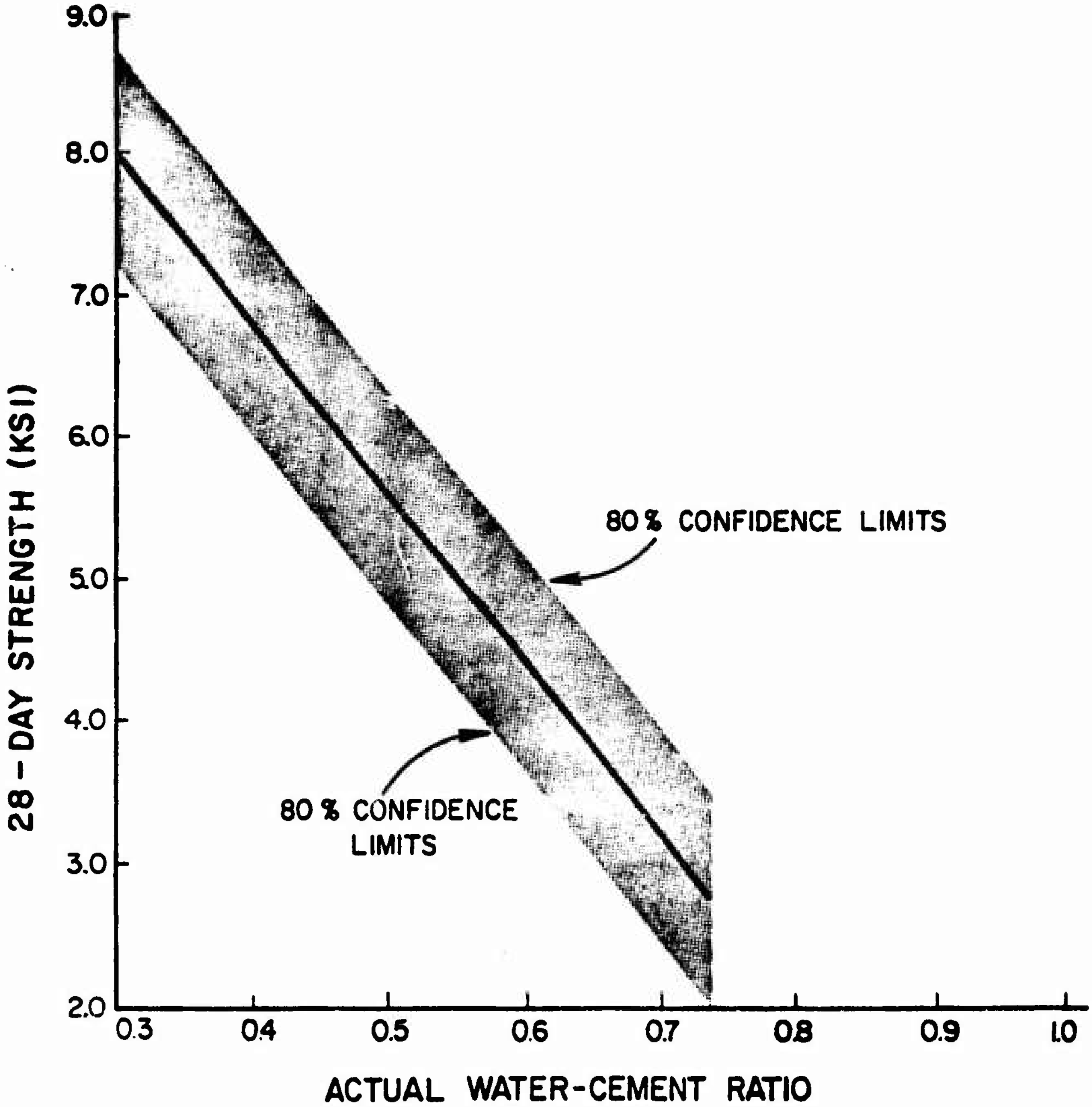

Figure 7. Water-cement ratio vs 28-day compressive strength.

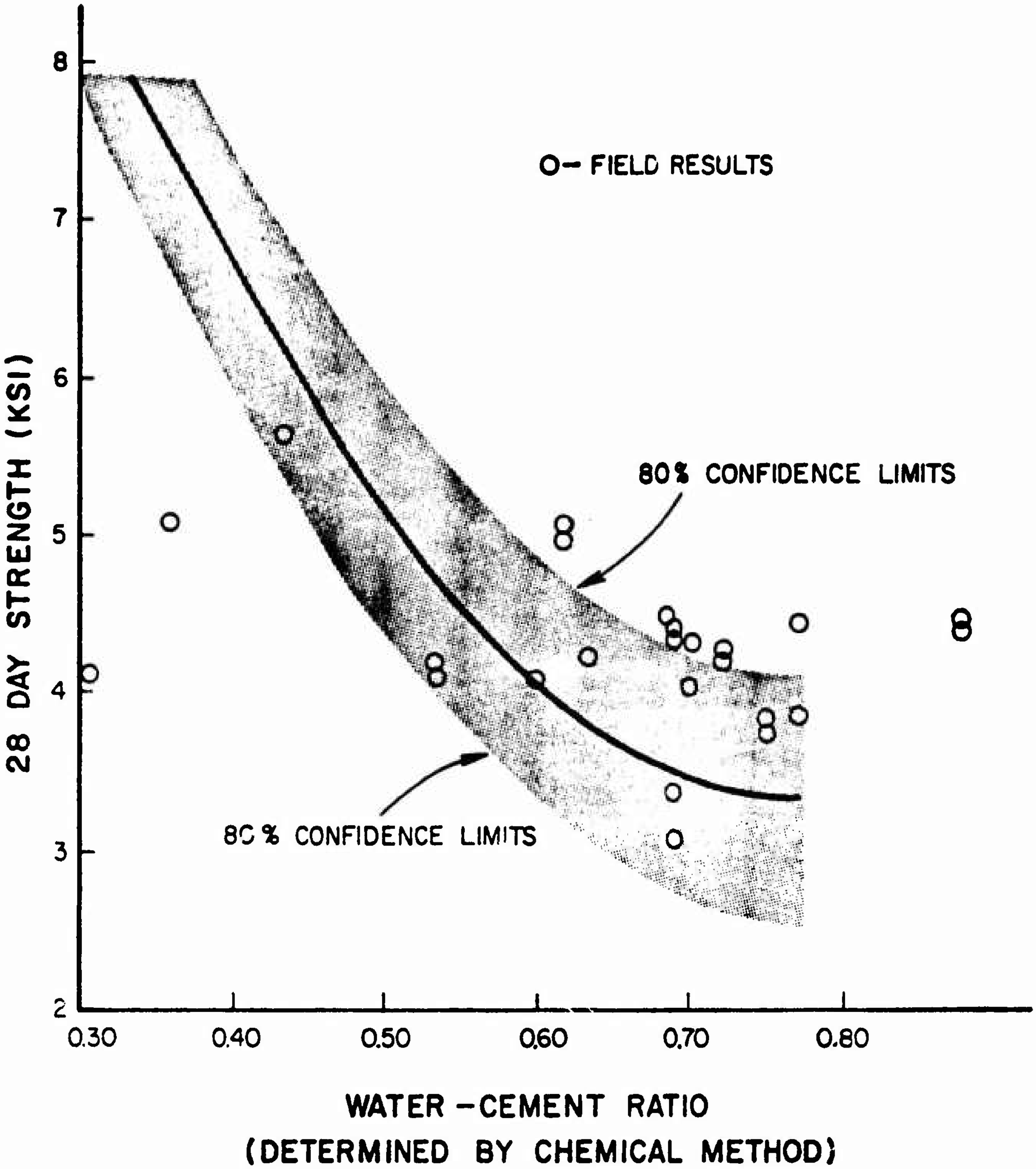

Figure 8. Water-cement ratio vs 28-day compressive strength.

Table 1

Laboratory Mixes - Batch Data

Batch No.	Aggregate Type *	Coarse Aggregate Moisture (%)	Coarse Aggregate Mix Prop. (%)	Fine Aggregate Moisture (%)	Fine Aggregate Mix Prop (%)	Cement Mix Prop. (%)	Water Free (%)	Water Total (%)	Water/Cement *	Strength 7-day Avg (psi)	Strength 28-day Avg (psi)	Slump (in.)	Mix Time (min)
1	MdQ	.56	48.5	7.86	24.6	18.40	8.39	8.73	.45	3600	4785	-	5
2	MdQ	.96	49.0	12.01	31.4	14.24	8.80	9.18	.62	2590	3585	-	5
3	MdQ	.41	49.3	15.38	34.4	11.71	8.85	9.25	.75	1470	2420	-	5
4	MdQ	.44	49.0	16.74	32.6	14.24	8.64	9.02	.61	2640	3910	-	45
5	L-S	1.30	41.8	6.20	31.4	19.55	8.74	9.62	.45	5258	6460	-	5
6	L-S	1.40	42.1	6.30	36.0	15.14	8.54	9.47	.56	4250	5494	8.0	5
7	L-S	1.20	42.4	6.40	38.4	12.57	8.53	9.49	.68	2700	4061	-	5
8	L-S	1.30	42.1	5.70	35.9	15.14	8.42	9.35	.56	4062	5382	5.5	45
9	L-S	0.10	41.8	0.40	29.9	19.55	7.91	8.80	.40	5612	6910	6.5	5
10	L-S	0.09	42.1	0.40	34.0	15.14	8.02	8.95	.53	4310	5335	8.5	5
11	L-S	0.10	42.4	0.50	36.2	12.57	8.08	9.02	.64	3024	4085	8.0	5
12	L-S	0.10	42.1	0.40	34.0	15.14	8.02	8.96	.53	4062	5215	3.0	45
13	MdQ	0.07	49.0	0.15	28.5	14.24	7.89	8.28	.55	3431	4290	4.5	5
14	MdQ	0.05	49.0	0.15	28.5	14.24	7.88	8.27	.55	3349	4005	1.5	45
15	G-S	3.12	34.6	3.67	33.2	23.70	9.00	10.59	.38	6550	7460	6.0	5
16	G-S	3.32	35.0	3.69	39.8	16.84	9.12	10.80	.54	4186	5390	9.0	5
17	G-S	3.33	35.2	3.00	42.9	13.49	9.04	10.76	.67	2730	3930	9.5	5
18	G-S	3.20	34.9	4.26	40.4	16.79	8.97	10.65	.53	4304	5220	4.0	45
19	G-S	0.36	34.6	0.22	32.3	23.62	7.97	9.61	.34	6733	7670	1.0	5
20	G-S	0.32	34.9	0.21	38.8	16.79	7.98	9.69	.48	4710	5750	4.5	5
21	G-S	0.32	35.2	0.19	41.7	13.48	8.01	9.77	.59	3215	4140	3.5	5
22	G-S	0.27	34.9	0.21	38.8	16.79	7.96	9.68	.47	4740	5770	1.0	45

* MdQ = Maryland Quartz Coarse (Absorption Cap. = .35%)
Maryland Quartz Fine (Absorption Cap. = .75%)
L-S = Crushed Limestone Coarse (Absorption Cap. = 1.30%)
River Sand Fine (Absorption Cap. = 1.15%)
G-S Gravel Coarse (Absorption Cap. = 3.65%)
River Sand Fine (Absorption Cap. = 1.15%)

** Water-Cement Ratio based on Free Water Content

Table 2

Test on Concrete Samples - Water and Cement Content

Batch No.	Batch Proportions: Free Water %	Batch Proportions: Total Water %	Batch Proportions: Cement %	Sample No.	Test Results: Water	Test Results: Cement	Recovery: Free Water	Recovery: Total Water	Recovery: Cement
1	8.39	8.73	18.40	1	7.45	17.75	88.8	85.3	96.5
				2	8.15	17.80	97.1	93.4	96.7
2	8.80	9.[illegible]	[illegible]4.24	1	7.80	1[illegible].30	88.[illegible]	85.[illegible]	93.4
				2	8.15	12.25	92.6	88.[illegible]	86.0
3	8.85	9.25	11.71	1	8.81	11.40	99.5	95.2	97.4
				2	8.45	12.65	95.5	91.4	108.0
4	8.64	9.02	14.24	1	8.15	13.25	93.2	84.7	93.3
				2	8.15	12.15	93.2	84.7	85.3
5	6.74	9.6[illegible]	19.55	1	7.80	19.62	89.2	81.1	100.3
				2	8.15	20.05	93.2	84.[illegible]	102.6
6	8.54	9.47	15.14	1	7.80	16.87	91.3	82.4	111.4
				2	8.44	17.25	98.8	89.1	113.9
7	8.53	9.49	12.57	1	8.15	13.30	95.5	86.[illegible]	105.8
				2	8.15	13.38	95.5	86.1	106.4
8	8.42	9.35	15.14	1	7.47	15.58	88.7	79.9	102.9
				2	7.80	16.30	92.6	83.4	107.7
9	7.91	8.80	19.55	1	7.80	20.15	98.6	88.6	103.1
				2	7.80	19.15	98.6	88.6	98.0
10	8.02	8.95	15.14	1	7.65	16.50	95.4	85.5	109.0
				2	7.95	16.15	99.1	88.8	106.7
11	8.08	9.02	12.57	1	7.65	12.80	94.7	84.8	101.8
				2	8.15	14.40	100.9	90.3	114.6
12	8.02	8.95	15.14	1	7.45	15.00	92.9	83.1	99.1
				2	7.45	14.20	92.9	83.1	92.2
13	7.89	8.28	14.24	1	7.30	12.25	92.5	88.2	86.0
				2	7.30	13.80	92.5	88.2	96.9
14	7.88	8.27	14.24	1	7.45	12.25	94.5	90.1	86.0
				2	7.80	13.75	99.0	94.3	96.9
15	9.00	10.59	23.70	1	8.45	24.70	93.9	79.8	104.2
				2	8.45	21.25	93.9	79.8	89.7
16	9.12	10.80	16.84	1	8.82	16.45	96.7	81.7	97.9
				2	8.82	16.20	96.7	81.7	96.2
17	9.04	10.76	13.49	1	9.50	13.00	105.1	88.3	96.4
				[illegible]	[illegible].16	10.2[illegible]	101.[illegible]	85.[illegible]	76.0
18	8.97	10.65	16.79	1	[illegible].16	15.90	102.1	86.0	94.7
				2	9.16	15.97	102.1	86.0	95.1
19	7.97	9.61	23.62	1	7.96	22.85	99.7	82.1	96.7
				2	8.15	22.45	102.1	84.1	95.0
20	7.98	9.69	16.79	1	7.96	15.55	99.7	82.1	92.6
				[illegible]	[illegible]	15.4[illegible]	102.[illegible]	84.[illegible]	9[illegible]
21	8.01	9.77	13.48	1	8.15	12.95	101.7	83.4	96.1
				2	8.15	13.18	101.7	83.4	97.8
22	7.96	9.68	16.79	1	8.15	16.15	102.4	84.2	96.2
				2	8.15	14.80	102.4	84.2	88.1

	Free Water	Total Water	Cement
Overall mean and standard deviation	$\bar{X}$=96.56 $S_{\bar{X}}$ 4.40	$\bar{X}$=85.70 $S_{\bar{X}}$= 3.74	$\bar{X}$-97.79 $S_{\bar{X}}$= 3.06
Mean and standard deviation for Maryland Quartz Agg. (Batch No. 1, 2, 3, 4, 13, 14)	$\bar{X}$=94.17 $S_{\bar{X}}$= 3.68	$\bar{X}$=89.11 $S_{\bar{X}}$= 3/82	$\bar{X}$=93.53 $S_{\bar{X}}$= 6.77
Mean and standard deviation for Limestone-Sand Agg. (Batch No. 5-12)	$\bar{X}$=94.87 $S_{\bar{X}}$= 3.62	$\bar{X}$=85.35 $S_{\bar{X}}$= 3.09	$\bar{X}$=104.77 $S_{\bar{X}}$= 5.96
Mean and standard deviation for Gra[illegible]-Sand Agg. (Batch No. 15-22)	$\bar{X}$=100.23 $S_{\bar{X}}$= 3.25	$\bar{X}$=83.50 $S_{\bar{X}}$= 2.27	$\bar{X}$=94.03 $S_{\bar{X}}$= 6.03

Table 3

Errors in Strength Predictions
(80 Percent Confidence Limits)

Sample Group	Error in Predicting Actual W/C	Error in Test Data (psi)	Strength Prediction Actual (psi)
All	±.078	±780	±720
Quartz	±.060	±550	±175
Limestone-Sand	±.025	±350	±480
Gravel-Sand	±.046	±500	±335

Table 4

Field Test on Concrete Samples -- Water and Cement Content

Test No.	Mix Proportions Water %	Mix Proportions Cement %	Test Results Water %	Test Results Cement %	Recovery Water %	Recovery Cement %
1	9.85	19.8	10.5	15.5	106.5	78.4
2	9.85	19.8	9.5	15.2	96.0	76.8
3	9.85	19.8	9.2	15.4	93.3	77.7
4	7.21	19.2	7.1	16.9	99.0	87.7
5	7.21	19.2	6.83	19.5	94.7	101.3
6	6.92	12.4	7.48	10.3	108.0	83.0
7	7.60	11.8	7.15	10.3	94.0	87.2
8	7.60	11.8	7.80	10.2	102.5	86.5
9	7.60	11.8	8.15	11.0	107.0	93.2
10	7.60	11.8	7.80	12.8	102.5	108.5
11	7.60	11.8	8.15	11.9	107.0	100.7
12	7.60	11.8	8.15	15.4	107.0	130.5
13	7.60	11.8	7.15	8.1	94.0	68.6
14	7.60	11.8	8.15	11.4	107.0	96.6
15	7.60	11.8	7.15	7.2	94.0	61.0
16	7.60	11.8	6.2	20.4	81.5	94.39
				Overall Mean	99.62	94.39
				Standard Deviation	7.52	26.6